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PRELIMINARY NOISE TESTS OF THE
ENGINE-OVER-THE-WING CONCEPT
II. 10°-20° FLAP POSITION

by Meyer Reshotko, William A. Olsen, and Robert G. Dorsch
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Cleveland, Ohio
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INTRODUCTION

· Short takeoff and landing (STOL) aircraft will be using airports located close to large population centers. The noise generated by these airplanes must therefore be at levels acceptable to the nearby community. This is a difficult engineering task because the employment of lift augmentation devices may generate and/or redirect noise. For example, the use of externally blown flaps for lift augmentation results in considerable flap interaction noise (refs. 1-4).

A possible solution to the STOL and CTOL (Conventional Takeoff and Landing) noise problems is to locate the engines above the wing. By placing the engines over the wing, shielding by the wing can reduce the exhaust noise at both the flyover and sideline locations. However, in order to obtain the required lift augmentation for STOL aircraft, the engine exhaust flow must be attached to the wing and flaps.

This report is the second part of a series summarizing the results of preliminary acoustic tests of the engine-over-the-wing concept. The

tests were conducted at the NASA Lewis Research Center with a small wing

section model (32 cm chord) having two flaps which can be set for either

the landing or takeoff positions. The flap angles at the landing posi-

tion are 30° and 60° respectively, and the corresponding noise data are

reported in reference 5. The flap angles at the takeoff position are 10°

and 20° respectively. The data taken with the flaps in the takeoff posi-

tion are reported herein. The engine exhaust was simulated by an air jet

from a convergent nozzle having a nominal or equivalent diameter of 5.1

centimeters. Far field noise data are presented for nominal pressure

ratios of 1.25, 1.4 and 1.7 for both the flyover and sideline modes.

Factors investigated for their effect on noise include exhaust deflectors,

wing shielding, flap-slot covering, nozzle shape, nozzle location, and

internally generated exhaust noise.

APPARATUS

A typical setup for conducting noise tests on the engine-over-the-

wing model with muffler, nozzle, wing and microphones in place is shown

in figure 1. Test configurations with both a slot and a circular nozzle

in place over the wing are shown in figure 2. All tests were conducted

with the wing at a 5° angle of attack with respect to the nozzle center-

line and with the flaps at the 10°-20° position. Details of the wing and

flap system are given in reference 1. The wing was moved to various

positions under the nozzle and the relative nozzle locations with respect

to the wing are shown in figure 3(a). Two nozzles were used in the test series, a circular nozzle with a nominal 5.1 centimeter diameter and a slot nozzle with an aspect ratio of 5, both having the same cross-sectional area (20.4 cm^2). In order to be able to vary the chordwise location of the flow exit plane the circular nozzle had an extended 26 centimeter long lip (fig. 2(b)). Each nozzle was supplied by pressurized air at a temperature of about 278 K. Data were obtained at nominal jet velocities within a range of 175 to 280 m/sec (nominal pressure ratios of 1.25 to 1.7, respectively). The air supply system contained a series of mufflers which removed sufficient valve noise to assume that it was not included in the measured noise. The exhaust deflector plate used to attach the flow to the wing and flaps is shown in figure 3(b) for the circular nozzle.

In order to evaluate the noise effect of the jet passing over the slot leading edges, the slots were partially or fully covered in some runs as shown in figure 4. In figure 4(a) the second slot is covered chordwise with 10.2 centimeter wide tape centered under the jet, while in figure 4(b) the first slot is covered in a similar manner and in figure 4(c) both slots are thus covered. In figure 4(d) the wing and slots are fully covered spanwise as well.

Flyover noise was measured with the wing-flap system making a 90° angle with the microphone plane, which was horizontal (fig. 5(a)). Sideline noise measurements were taken with the nozzle and wing-flap system making a 26.5° angle with the microphone plane (fig. 5(b)).

Sound data were taken by microphones placed on a 3.05 meter radius centered at the nozzle exit. The microphone horizontal plane and jet centerline were located 1.5 meters above the ground. The sound data were analyzed by a 1/3 octave band spectrum analyzer. The analyzer determined sound pressure level spectra referenced to 2×10^{-5} N/m^2 (0.0002 microbar). Overall sound pressure levels were computed from the SPL data. A typical setup for noise measurement is illustrated in figure 6 where the microphones are appropriately placed on the circle.

In some runs an orifice plate was used to create a dominant internal noise in the nozzle exhaust flow, which exceeded all the aerodynamic noises of the experiment. The orifice plate contained four 1.1 centimeter diameter holes and was located 2.04 meters upstream of the nozzle exhaust plane.

RESULTS

In order to evaluate possible acoustic benefits associated with the engine-over-the-wing concept, the measured noise data presented herein are compared to the noise of the nozzle alone. Although the data are separated into two main categories; namely, with and without internal noise, most of the data are presented for the case of no internal noise. The data without internal noise are additionally separated into those configurations in which flow was not attached to the wing-flap surfaces and those in which substantially complete flow attachment to the surfaces

was achieved. Furthermore, the data in each of these categories are presented for both flyover and sideline noise.

WITHOUT INTERNAL NOISE

Unattached Flow

Nozzle alone. - A typical nozzle noise radiation pattern is shown in figure 7(a) where the OASPL for the circular nozzle is plotted as a function of the angle measured from the nozzle inlet. The data shown are for pressure ratios of 1.23, 1.38 and 1.70. Also shown in figure 7(b) are the sound pressure level spectra for the circular nozzle at an angle of 100° for the three pressure ratios. The 100° position was chosen because it is approximately under the wing when the airplane is in the takeoff attitude. The slot nozzle data are similarly shown in figures 8(a) and 8(b).

Flyover Noise

Wing shielding. - The 1/3 octave band spectral data for the circular nozzle in position c_1 over the wing-flap system are shown in figure 9. The data are presented in terms of SPL as a function of frequency at an angle of 100° with respect to the engine inlet for the nozzle pressure ratios of 1.23, 1.39 and 1.70, respectively. The data indicate that above 2,000 Hz the wing shields the jet noise at all three pressure ratios. At 20,000 Hz the engine-over-the-wing configuration is 5 dB quieter than the nozzle alone. Disregarding frequencies below 500 Hz because of background

noise the spectrum peak shifts to a reduced frequency at the low pressure ratio.

The noise radiation patterns presented in figure 10 are in terms of OASPL as a function of the angle from the nozzle inlet at the three pressure ratios and with various degrees of slot covering as a parameter. It should be noted that when comparing the spectral data of figure 9 to their corresponding OASPL's in figure 10 (triangle symbols at 100°) for wing shielding effects there is an apparent discrepancy. The spectral data show good wing shielding at the high frequencies while the noise radiation patterns show little or no wing shielding. This discrepancy appears because the OASPL is dominated by the peak values of SPL which occur at the low frequencies. This part of the spectrum is not shielded by the wing. The data in figure 10(a) show that for a pressure ratio of 1.23 the presence of the wing causes the jet to scrub along a portion of the wing surface resulting in an increase in OASPL below the wing. With no slot covering at all there is a noise increase of up to 10 dB above the nozzle alone. Covering the second slot chordwise with 10.2 centimeter wide tape under the jet centerline caused up to a 3 dB reduction in scrubbing noise under the wing. Covering the first slot only in a similar manner caused a decrease of up to 6 dB in the scrubbing noise. However, any further covering of the flap slots caused no further noise reduction. These data show that covering the flap slots in order to obtain a smooth contour causes a noise reduction where jet-flap interaction takes place. At the higher pressure ratios the same conclusion can be made as evidenced by the data in figures 10(b) and 10(c).

At a pressure ratio of 1.39 with optimum covering of the flap slots, the OASPL is the same as the nozzle-alone case (fig. 10(b)). At the highest pressure ratio (1.70) wing shielding becomes apparent when the slots are covered, causing a 2 dB noise reduction from the nozzle-alone case (fig. 10(c)). These small-scale data indicate that wing shielding becomes more apparent as jet velocity (or pressure ratio) increases because the OASPL due to the jet noise increases with the eighth power of the velocity while the scrubbing noise tends to increase the OASPL only as the sixth power of the velocity. This indicates that the scrubbing noise predominates at the lower pressure ratios.

The 1/3 octave band spectra for the slot nozzle in position c_1 over the wing-flap system at a microphone angle of 100° are shown in figure 11. The data indicate that above 2,000 Hz the wing and flaps shield the noise from the slot jet at all three pressure ratios. At 20,000 Hz the engine-over-the-wing configuration is about 8 dB quieter than the nozzle alone.

The noise radiation patterns taken with the slot nozzle in position c_1 over the wing flap system are shown in figure 12. The data in figure 12(a) show that for a pressure ratio of 1.23 the presence of the wing causes an increase in OASPL with respect to the nozzle alone between 0° and 100°. Because the jet from the slot nozzle is farther away from the wing surface than the circular jet (although the nozzle centerlines are identical) there is less jet interaction with the flap-slots and therefore the noise reduction obtained by covering the flap-slots is negligible. As the nozzle pressure ratio is increased (figs. 12(b) and 12(c))

there is a trend toward wing shielding similar to the previous case of the circular nozzle.

Nozzle location. - The effects of nozzle height and fore and aft location with respect to the wing on the noise radiation pattern are shown in figure 13 at various pressure ratios for a circular nozzle. The data in figure 13(a) at a pressure ratio of 1.23 show that when the nozzle is in the a_1 position the jet scrubbing causes an increase in OASPL of up to 7 dB below the wing. Moving the nozzle aft to the b_1 position caused up to a 5 dB reduction in scrubbing noise under the wing with respect to the a_1 position. Raising the nozzle to either the a_2 or b_2 location reduced the noise level to that of the nozzle-alone case. When the nozzle is in the a_2 or b_2 location no part of the jet interacts with the wing or flaps.

As the nozzle pressure ratio is increased (figs. 13(b) and 13(c)) there is a trend toward wing shielding of the jet noise. At the highest pressure ratio (1.70) where the jet noise dominates, there is no evidence of scrubbing noise under the wing for any nozzle location, while at the a_2 and b_2 nozzle locations there is a wing shielding effect of up to 3 dB

Sideline Noise

Wing shielding. - The sideline noise data taken with the circular nozzle in position c_1 over the wing flap system are shown in figure 14. For all nozzle pressure ratios the sideline noise level is between 0 and 3 dB less than comparable cases at flyover. Since the noise level for

the nozzle-alone case is the same in both the flyover and sideline configurations, there is a trend toward wing shielding of up to 3 dB at the sideline.

The sideline noise data taken with the slot nozzle in position c_1 over the wing flap system are shown in figure 15. For all nozzle pressure ratios the sideline noise level is between 0 and 2 dB less than that at flyover.

Attached Flow

As pointed out in the Apparatus section a deflector plate was used at the exit of the circular nozzle in order to direct the flow along the flap surfaces.

Flyover Noise

Nozzle alone with deflector. - The effect on noise level of the flow deflector for a circular nozzle at various pressure ratios is shown together with the same nozzle without a deflector in figure 16. The use of a flow deflector on the circular nozzle caused a large overall increase in nozzle alone noise, although the noise increase became less as the pressure ratio became greater. With a flow deflector in place the noise increases were 15, 11 and 8 dB for nozzle pressure ratios of 1.24, 1.39 and 1.70, respectively.

Nozzle with deflector and wing. - The 1/3 octave band spectra for a nozzle with flow deflector over the wing and flap system are shown in figure 17. The data are presented for nozzle pressure ratios of 1.26,

1.39 and 1.70 at a microphone angle of 100°. The data are compared to the nozzle-alone cases with and without flow deflectors in place. At frequencies above 2,500 Hz the data indicate that wing shielding takes place with respect to the nozzle-alone case with a deflector in place. At the very high frequencies, about 10,000 Hz, the engine-over-the-wing noise data is comparable to the nozzle-alone data without a deflector.

The noise radiation patterns are presented for the same three pressure ratios with various degrees of slot covering as a parameter. When the jet flow was attached to the wing-flap system by use of a deflector plate (fig. 18), the noise level increased significantly compared to the case with no deflector plate and no attachment (fig. 10). The data in figure 18(a) show that for a pressure ratio of 1.26 and no slot covering at all there is a noise increase under the wing of up to 6 dB above the nozzle alone case with deflector. Covering the second slot chordwise with 10.2 centimeter wide tape under the jet centerline caused no reduction in scrubbing or trailing edge noise under the wing. Covering the first slot only in a similar manner caused a 1 to 2 dB noise level decrease under the wing, and covering both slots caused a further decrease of up to 2 dB. When both slots were completely covered (chordwise and spanwise) there was up to a 6 dB reduction in scrubbing and trailing edge noise from the case where the slots were completely uncovered. For this case the jet attaches itself to the whole wingspan, unlike the case without a flow deflector (fig. 10) where the jet flows along a small portion of the wing span. Therefore covering the whole wingspan causes a further noise reduction with a flow deflector in place (fig. 18), while it has no

effect at all without a flow deflector (fig. 10(a)). At the higher pressure ratios the same conclusion can be made as evidenced by the data in figures 18(b) and 18(c)

Sideline Noise

Nozzle alone. - The effect of the flow deflector on sideline noise at various pressure ratios is shown together with the same nozzle without a deflector in figure 19. The sideline noise is slightly quieter than the flyover noise (fig. 16) for the region under the wing.

Nozzle with deflector and wing. - The sideline noise data taken with a nozzle flow deflector in the engine-over-the-wing configuration are shown in figure 20. The data are presented at the three pressure ratios and are compared to the nozzle-alone cases with and without flow deflectors in place. When the jet flow was attached to the wing-flap system with a nozzle flow deflector the sideline noise increased significantly compared to the case with no deflector and no attachment (fig. 14). For all nozzle pressure ratios the noise level at sideline (fig. 20) is between 0 and 3 dB less than at flyover (fig. 18).

WITH INTERNAL NOISE

Unattached Flow

Nozzle alone. - The noise increase caused by the dominant internal noise source (an orifice plate) inserted upstream of the nozzle exit plane is shown in figure 21(a) for the nozzle-alone case at a pressure ratio of 1.23. In general, the presence of this dominant internal noise

source caused an overall increase of 30 dB in the nozzle-alone noise level. Also shown in figure 21(b) are the sound pressure level spectra at an angle of 100° with and without an internal noise source. The internal noise source caused a large increase in SPL and shifted the center frequency to a higher frequency than that for the case without internal noise.

Since the level of the dominant internal noise source was arbitrary, only changes in noise level will be shown hereinafter.

Flyover Noise

Wing shielding. - The data in figure 22 show that the wing is an effective shield for the exhaust jet noise in which internal noise dominates. Under the wing, a large noise attenuation of up to 13 dB was obtained at a pressure ratio of 1.24.

Sideline Noise

Wing shielding. - The sideline noise data taken with a dominant internal noise source is shown in figure 23 for a pressure ratio of 1.24. The data show that with the 10°-20° flap setting the sideline noise is about the same as the flyover noise (fig. 22) through the 80° microphone location, 2 dB higher than flyover at 100°, and about 5 dB higher than flyover at 120° and 140°.

CONCLUDING REMARKS

An experimental investigation has been conducted in order to determine the noise effects obtained by locating the engine over the wing. A summary of results and some conclusions which can be drawn from these small scale tests are presented.

For the case of unattached flow the 1/3 octave band sound pressure level (SPL) spectra indicate that above 2,000 Hz wing shielding of jet noise takes place at all pressure ratios. At 20,000 Hz there is a noise attenuation due to wing shielding of 5 dB for the circular nozzle and 8 dB for the slot nozzle.

In order to obtain good flow attachment of the exhaust jet to the wing-flap system a deflector was employed with the circular nozzle. The 1/3 octave band SPL spectra show that above 2,500 Hz there is wing shielding at all pressure ratios with respect to the nozzle alone with deflector. At the very high frequencies (about 10,000 Hz) the engine-over-the-wing data are comparable to the nozzle-alone (without deflector) data.

When the small model data are scaled up to a full-sized aircraft, the SPL spectra shift to a lower frequency. Therefore, for a full-sized aircraft, the resultant noise attenuation due to wing shielding makes the engine-over-the-wing concept look quite favorable.

There were no appreciable differences between the acoustic results obtained with the flaps in the 30°-60° position (ref. 5) and the comparable cases for the 10°-20° flap position reported herein.

The noise at sideline was up to 3 dB quieter than that for flyover at the under the wing locations.

Covering the flap slots reduced scrubbing noise only in those cases where the jet interacted with the flap slots.

When the circular nozzle was placed relatively high above the wing (a_2 or b_2 positions in fig. 3), where there was no jet-flap interaction, a wing shielding effect of up to 3 dB at the high pressure ratio (1.70) was obtained. Although this is not applicable to lift augmented STOL aircraft, it may be applicable to CTOL aircraft.

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    NASA TM X-68032.
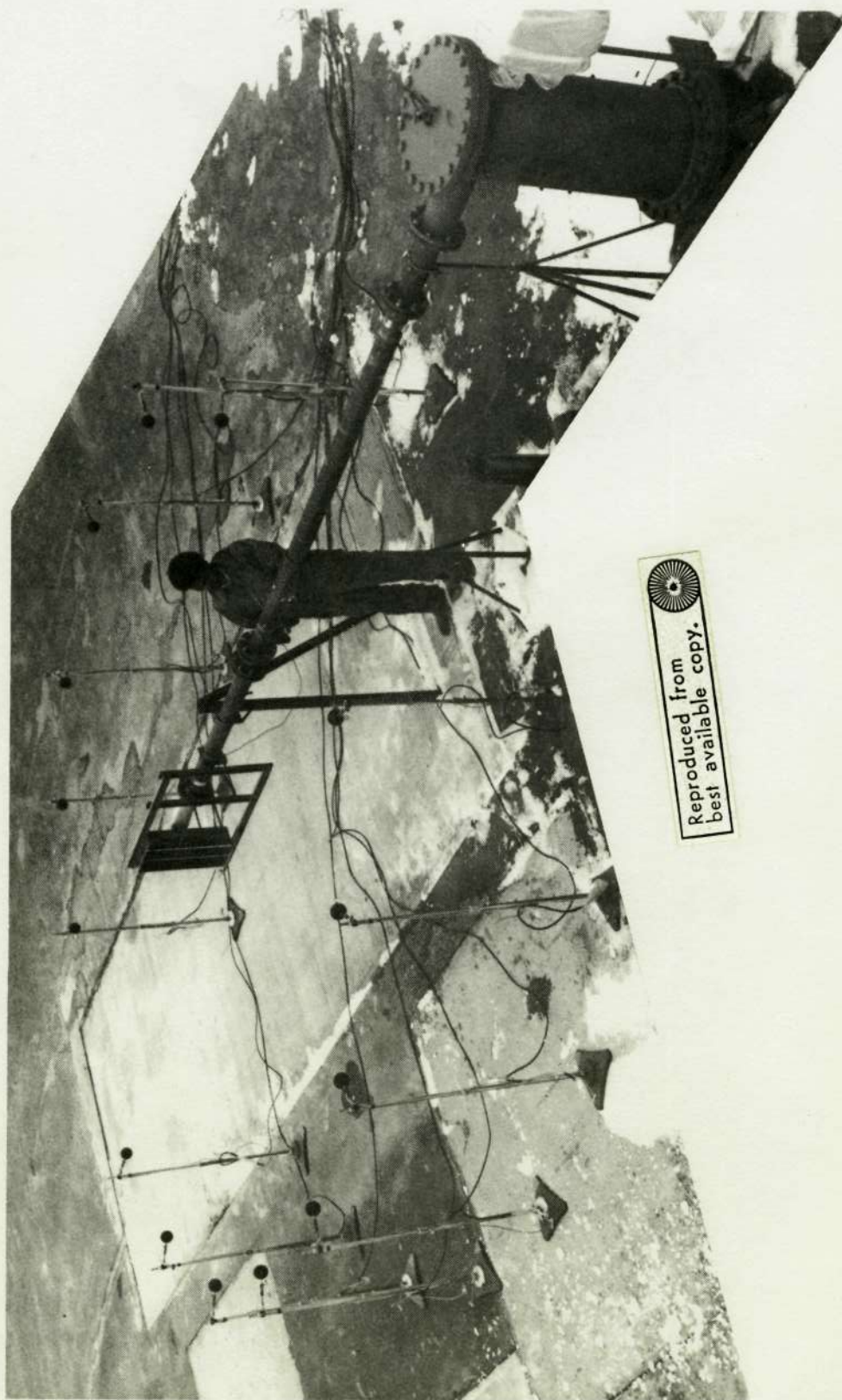
Figure 1. A typical setup for performing noise tests on the engine-over-the-wing model.
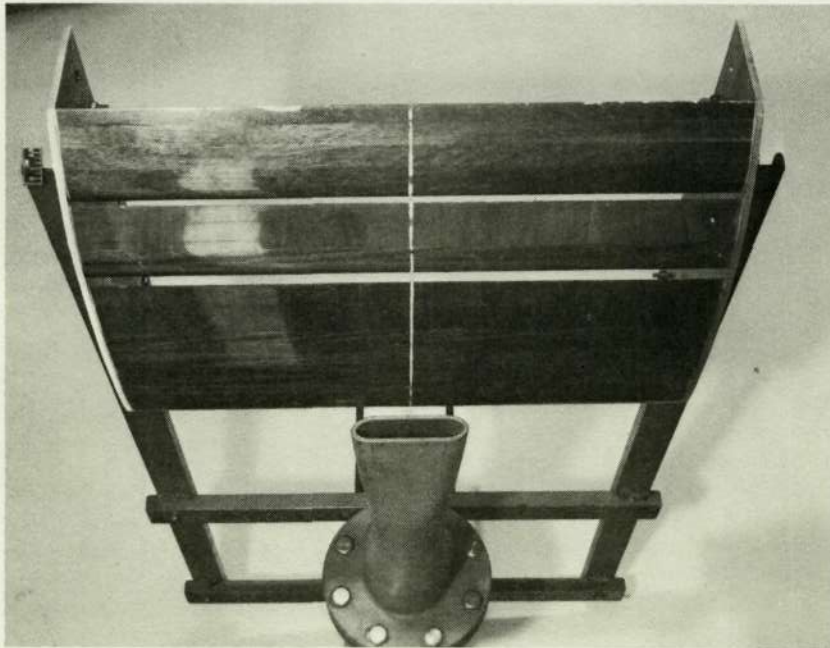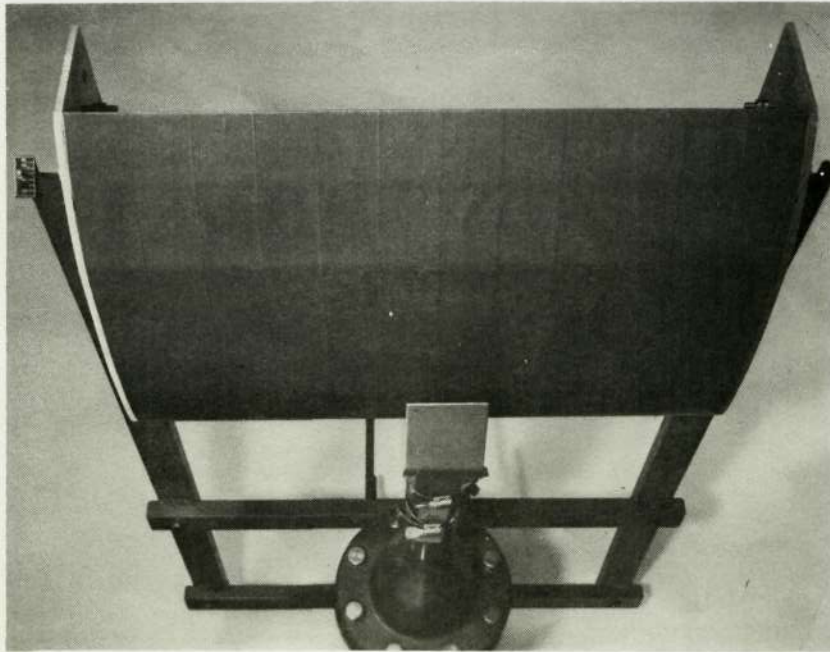
b. Circular nozzle with covered slots and deflector plate.

a. Slot nozzle.

Figure 2. Typical test configurations of the engine-over-the-wing model with the flaps in a 10°-20° position.
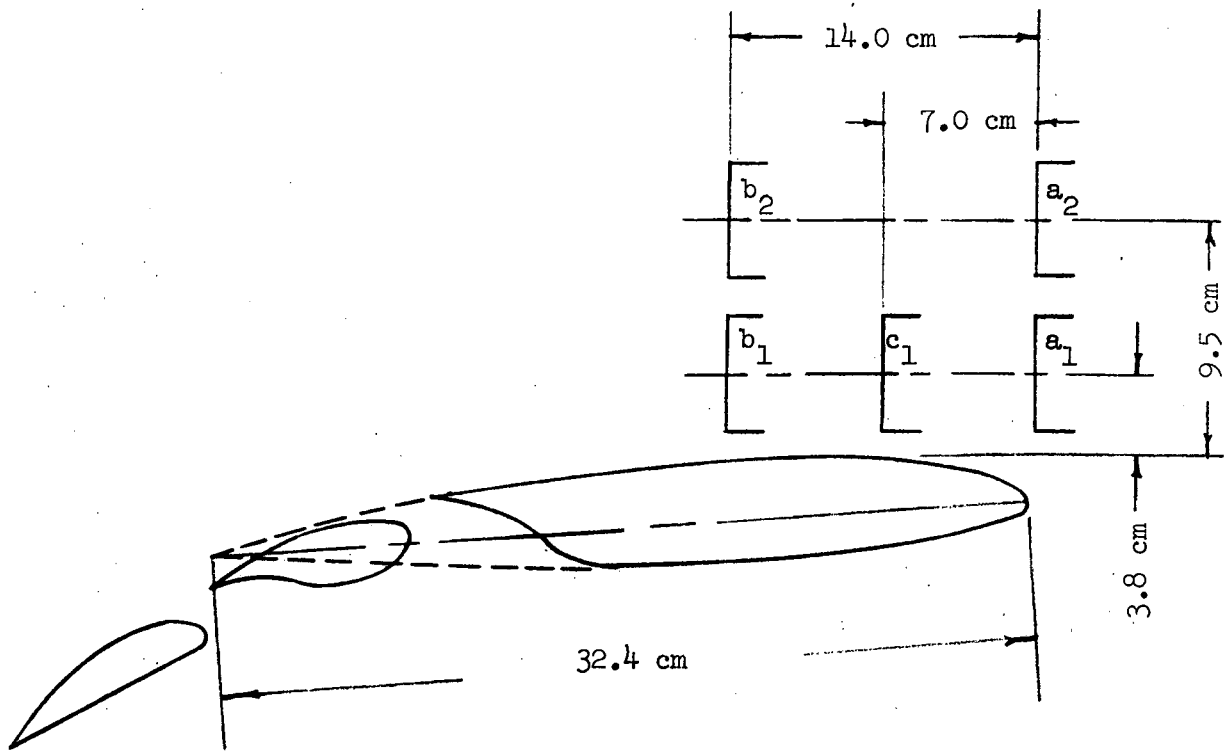
a. Nozzle locations with respect to the wing.
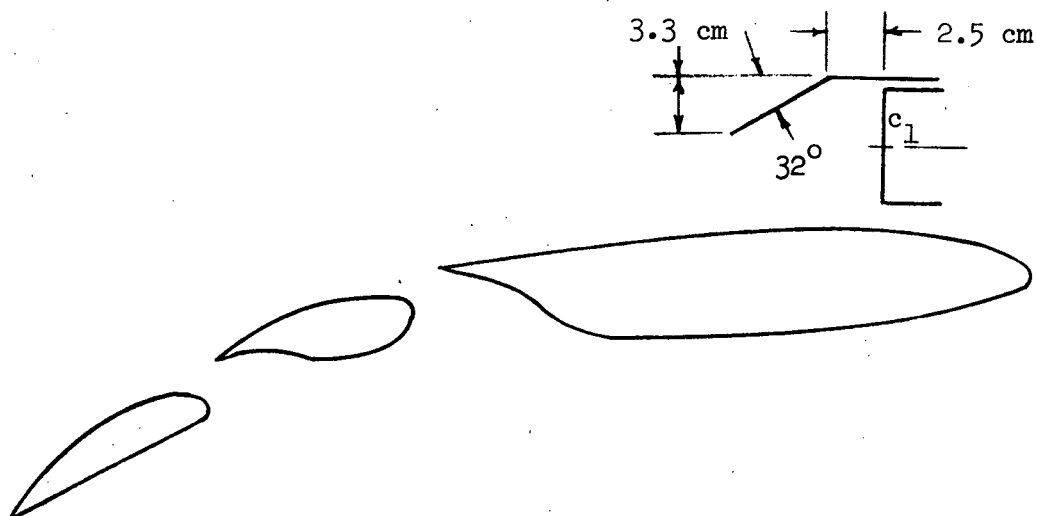
b. Circular nozzle with a 7.6 cm wide deflector.

Figure 3. Engine-over-the-wing test configuration.
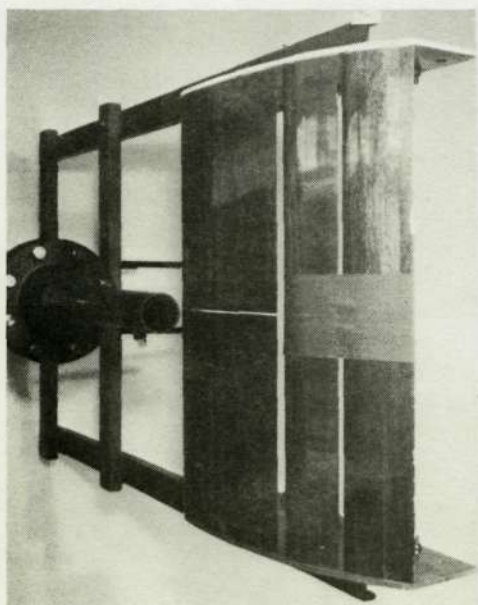
a. Second slot covered with a
   10.2 cm width of tape.
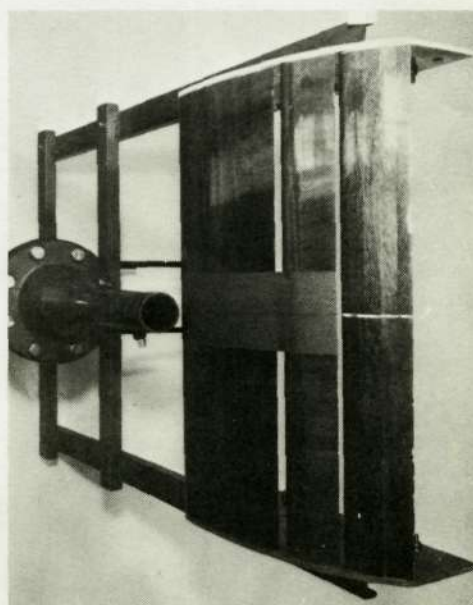
b. First slot covered with a
   10.2 cm width of tape.
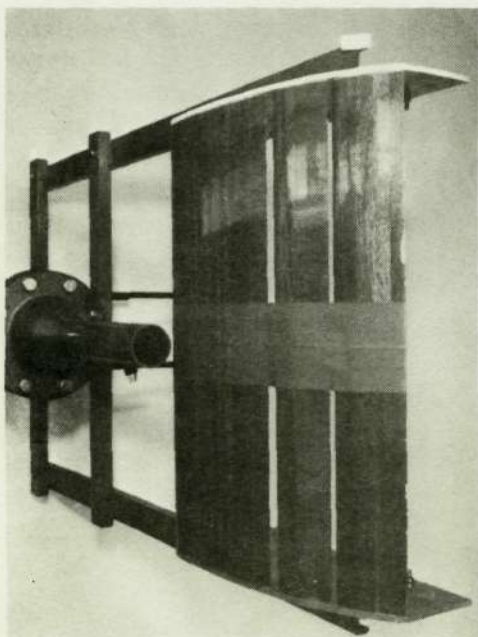
c. Both slots covered with a
   10.2 cm width of tape.
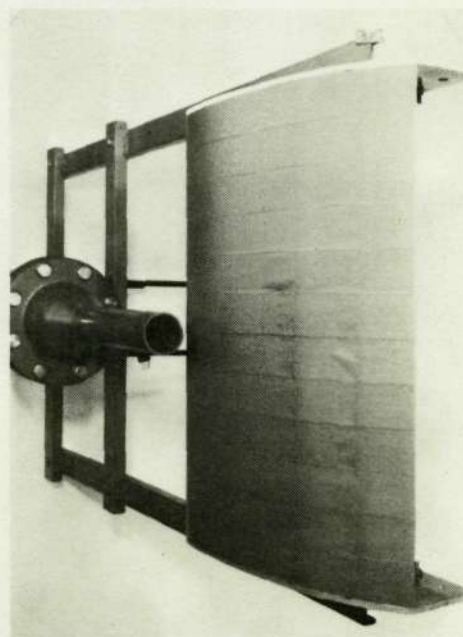
d. Fully covered slots.

Figure 4. The engine-over-the-wing model with various degrees of slot
          covering.
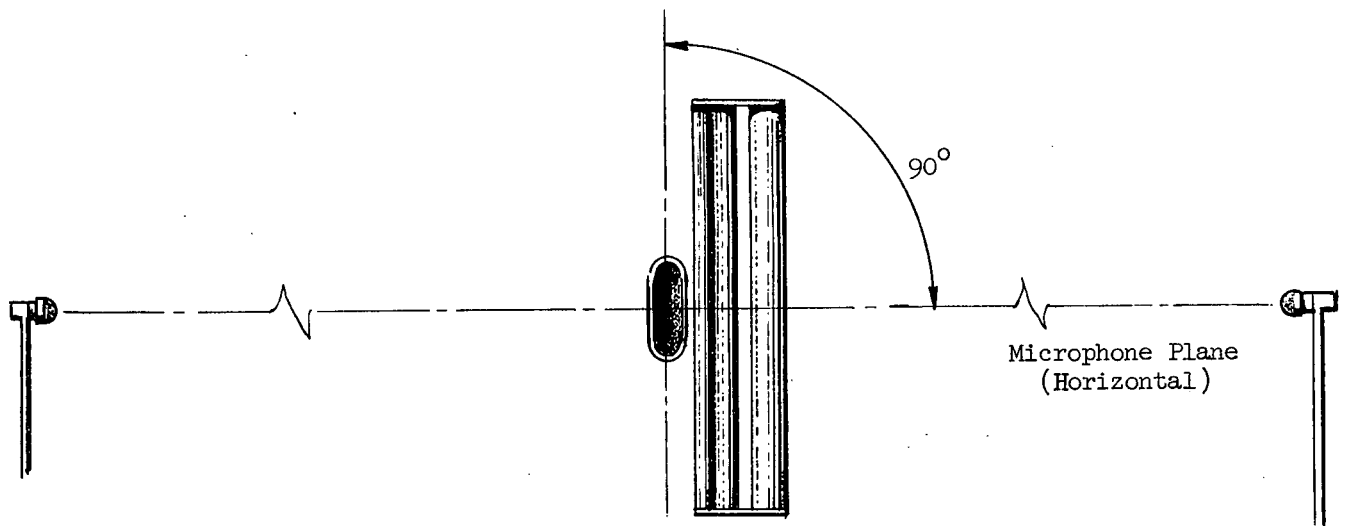
a. Flyover mode.
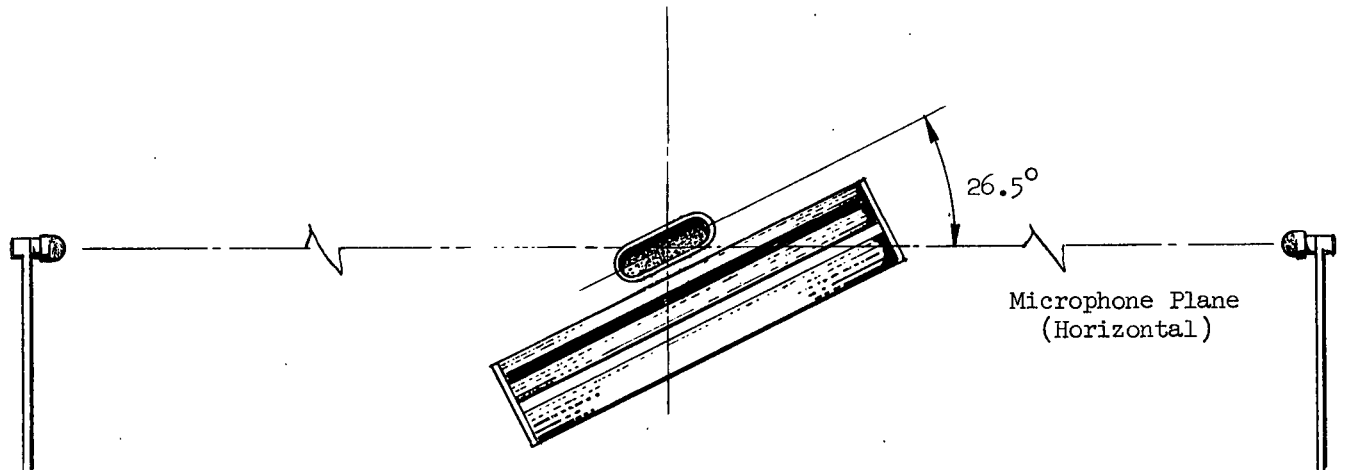
b. Sideline mode.

Figure 5. Typical test configurations of the engine-over-the-wing model in both flyover
and sideline modes.

270°

180°

3.05 m

0°

90°

14 microphones
appropriately
placed on this
circle
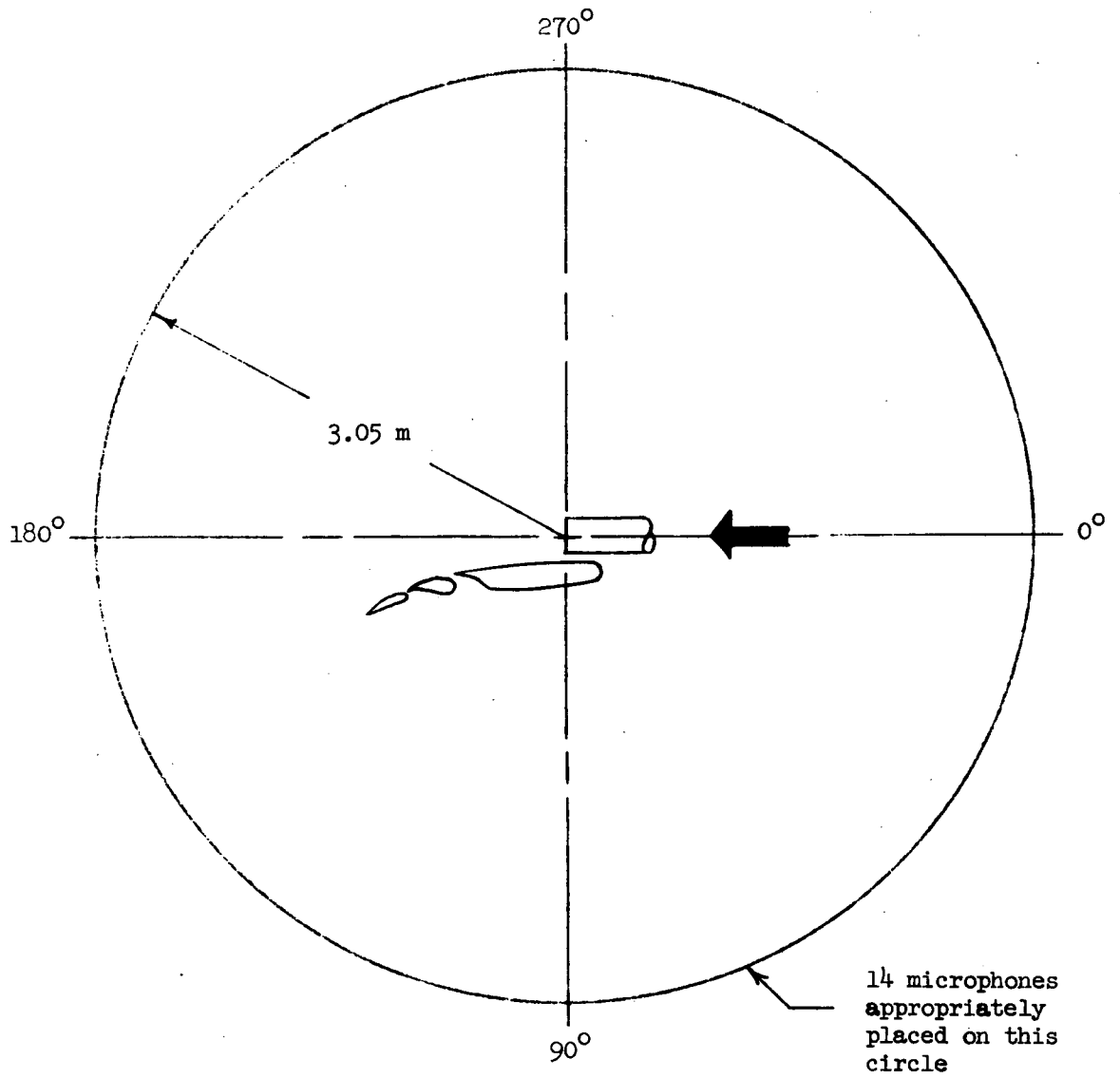
Figure 6. Microphone circle for small scale engine-over-the-wing model.
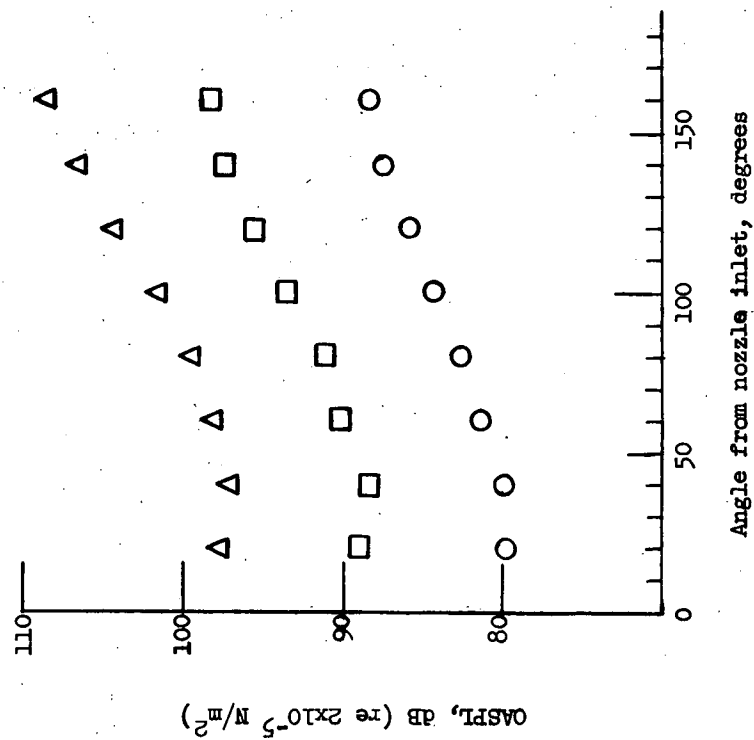
SPL, dB (re 2×10^{-5} N/m^2)

Frequency, Hz

	Pressure ratio	Jet velocity m/sec
△	1.70	278
□	1.38	221
○	1.23	178

b. One-third octave band sound pressure level spectra at 100°.

OASPL, dB (re 2×10^{-5} N/m^2)

Angle from nozzle inlet, degrees

a. Noise radiation pattern.
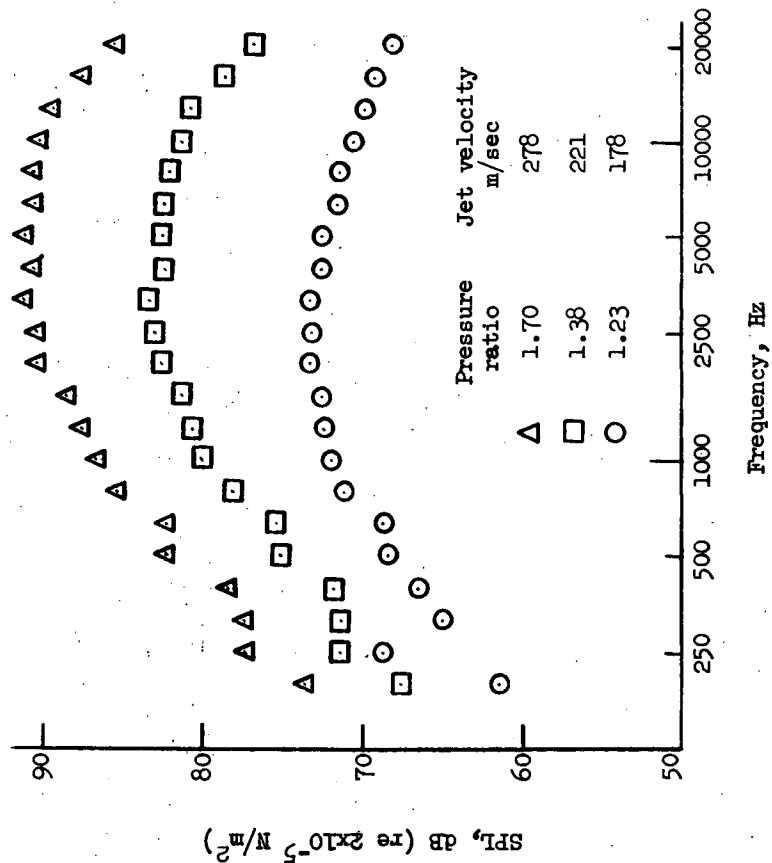
Figure 7. Comparison of noise data at various jet velocities and pressure ratios for the circular nozzle.

b. One-third octave band sound pressure level spectra at 100°.

a. Noise radiation pattern.
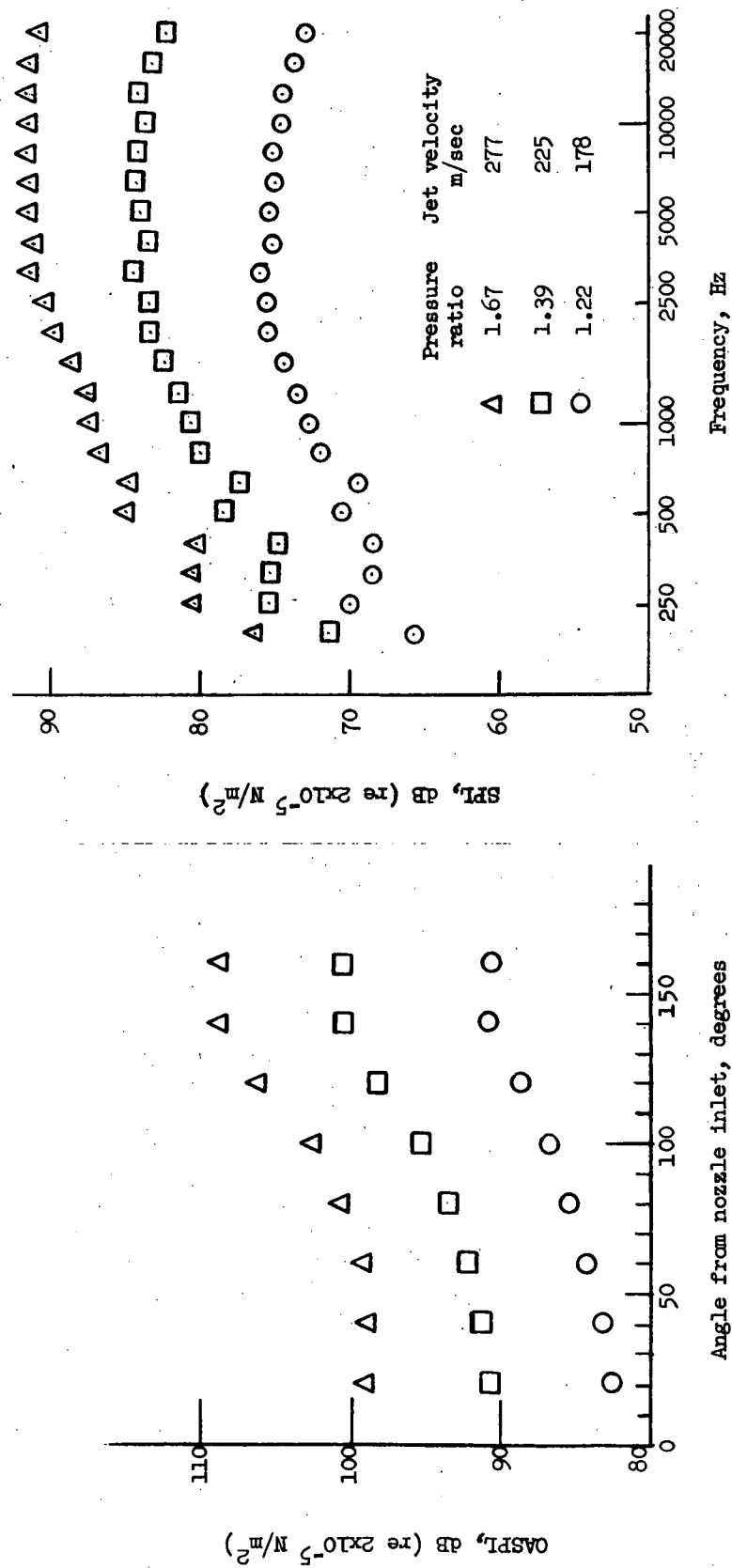
Figure 8. Comparison of noise data at various jet velocities and pressure ratios for the slot nozzle.
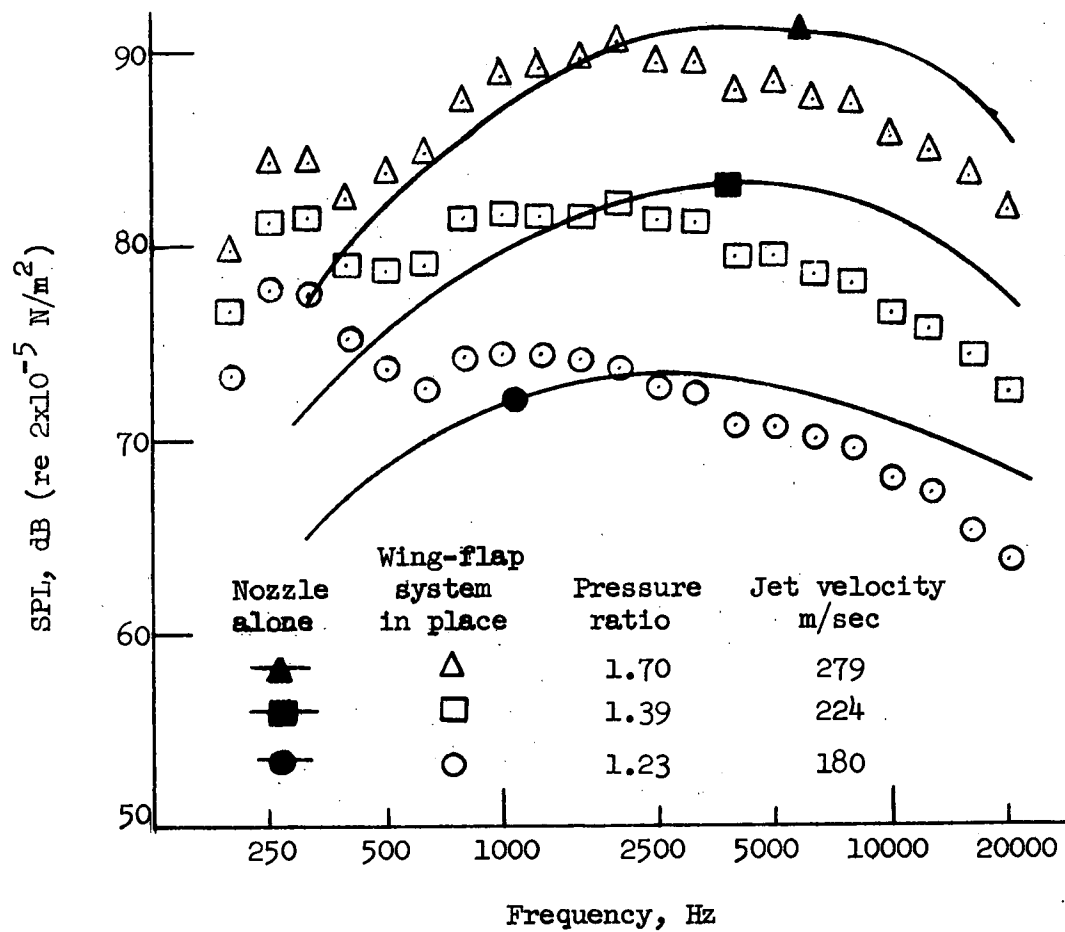
Figure 9. Effect of wing shielding on the 1/3-octave band spectra at various pressure ratios. Microphone angle, $100°$; circular nozzle; nozzle location, c_1; covered slots.
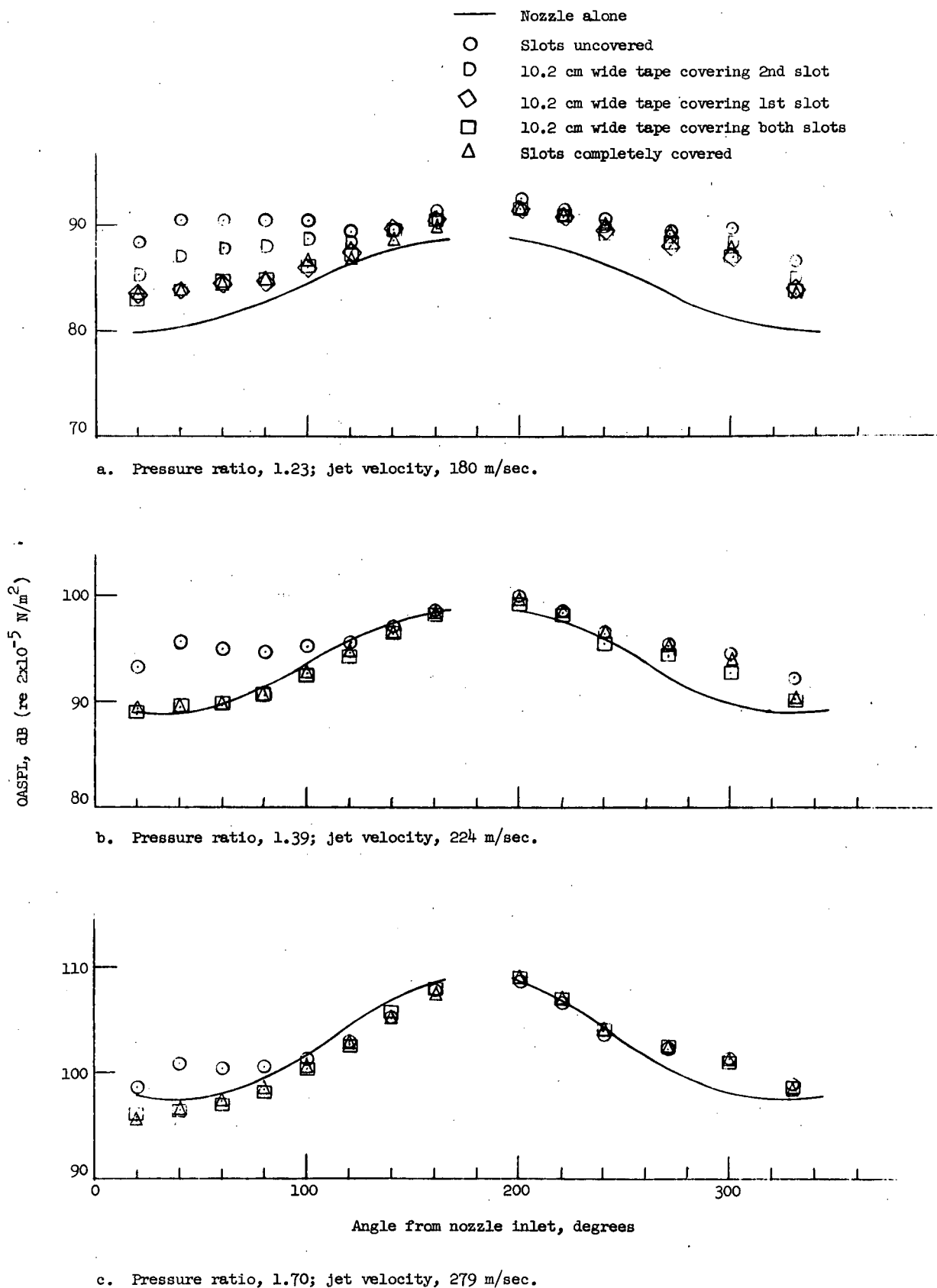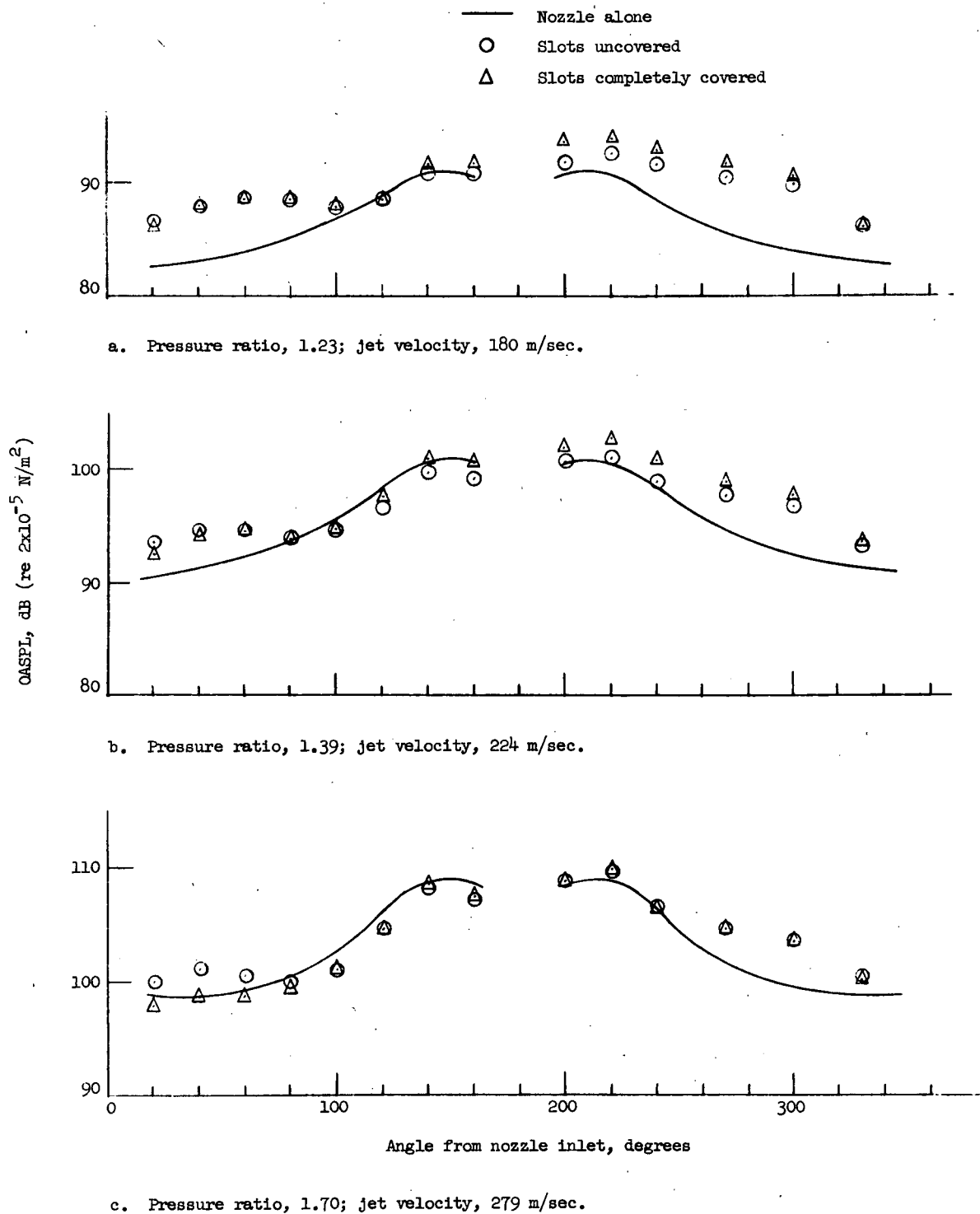
Figure 10. Effect of wing shielding and flap slot covering on the exhaust jet noise radiation pattern at various pressure ratios. Circular nozzle, nozzle location, c_1.
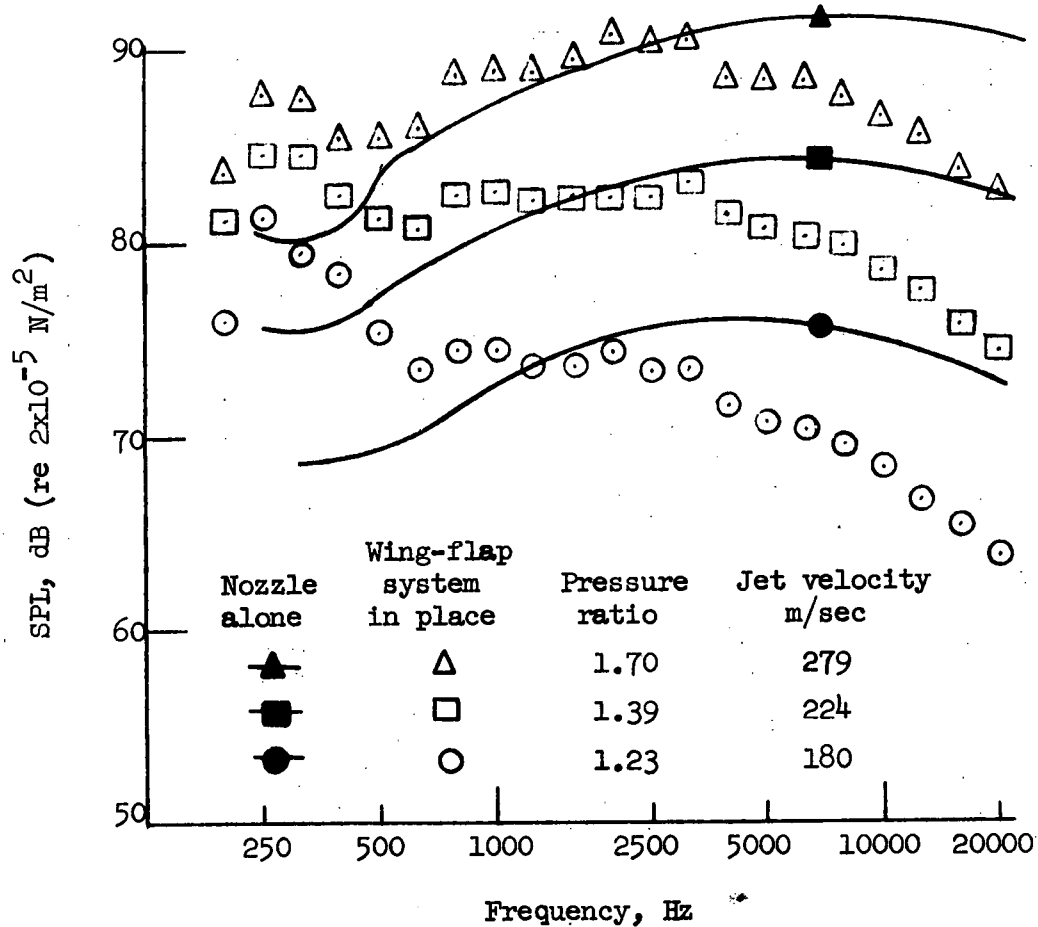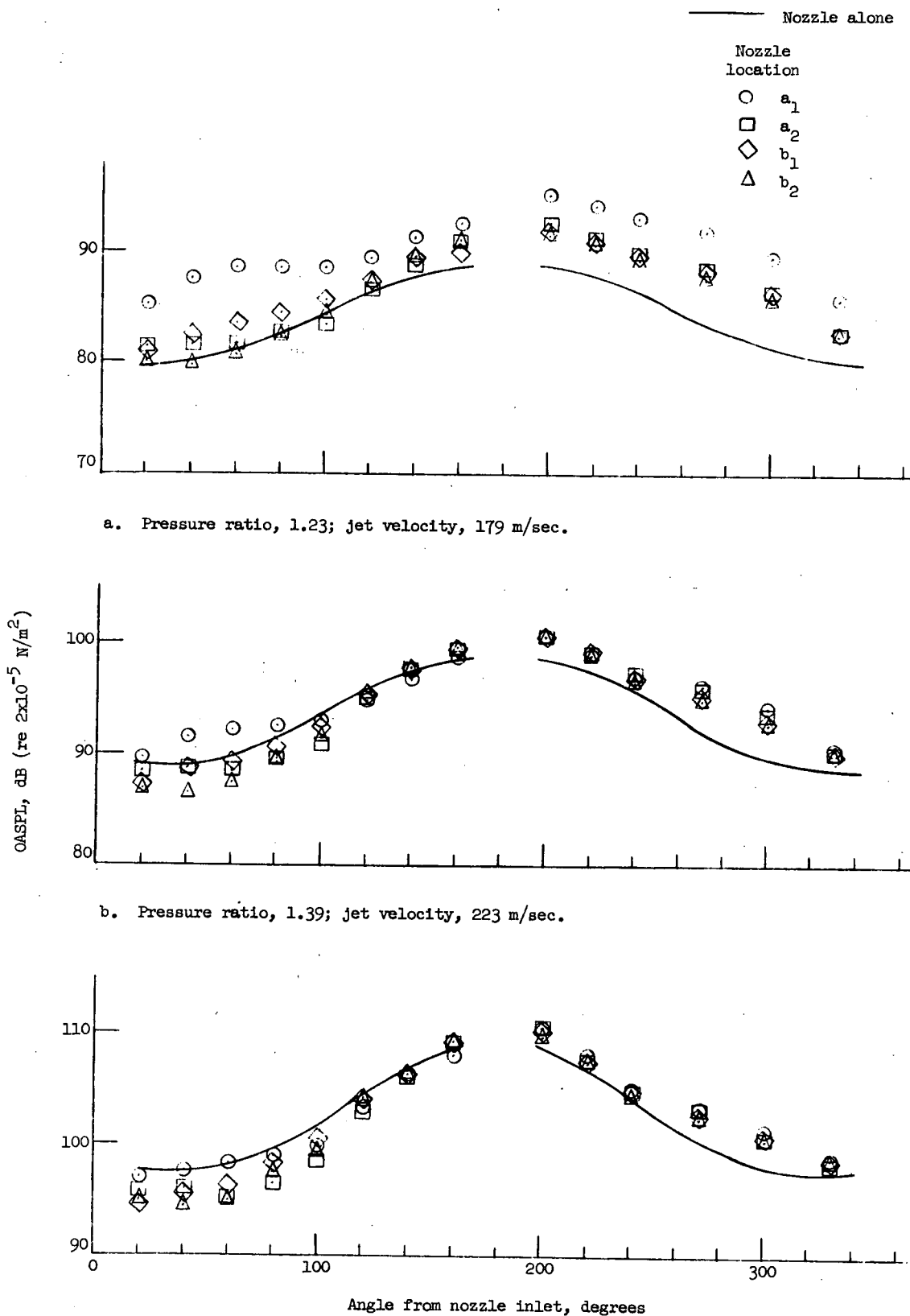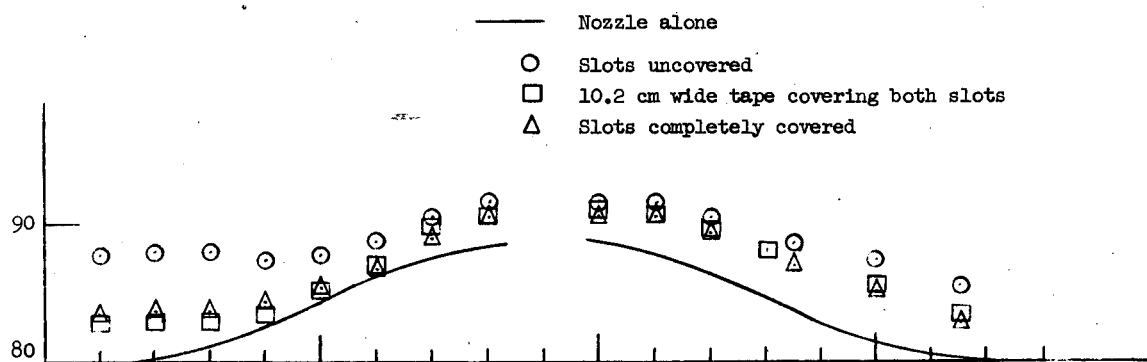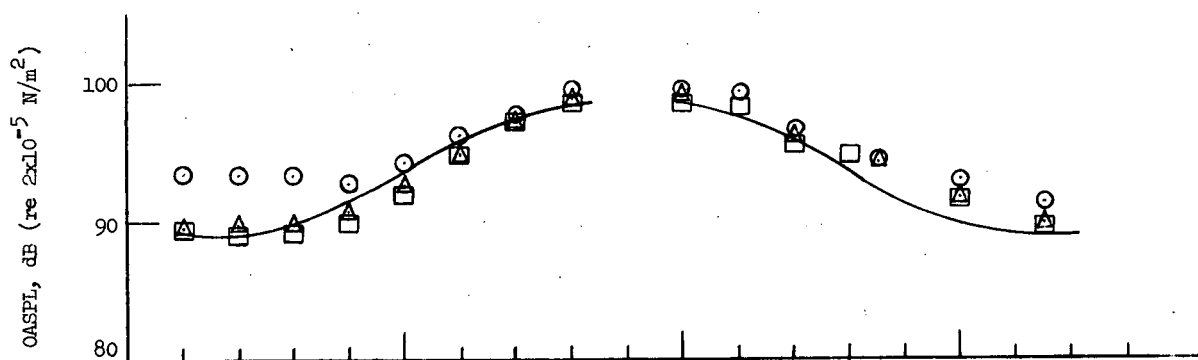
Figure 11. Effect of wing shielding on the 1/3-octave band spectra at various pressure ratios. Microphone angle, 100°; slot nozzle; nozzle location, c_1; covered slots.

a. Pressure ratio, 1.23; jet velocity, 180 m/sec.

b. Pressure ratio, 1.39; jet velocity, 224 m/sec.

c. Pressure ratio, 1.70; jet velocity, 279 m/sec.

Figure 12. Effect of wing shielding and flap slot covering on the exhaust jet noise radiation pattern at various pressure ratios. Slot nozzle; nozzle location, c_1.
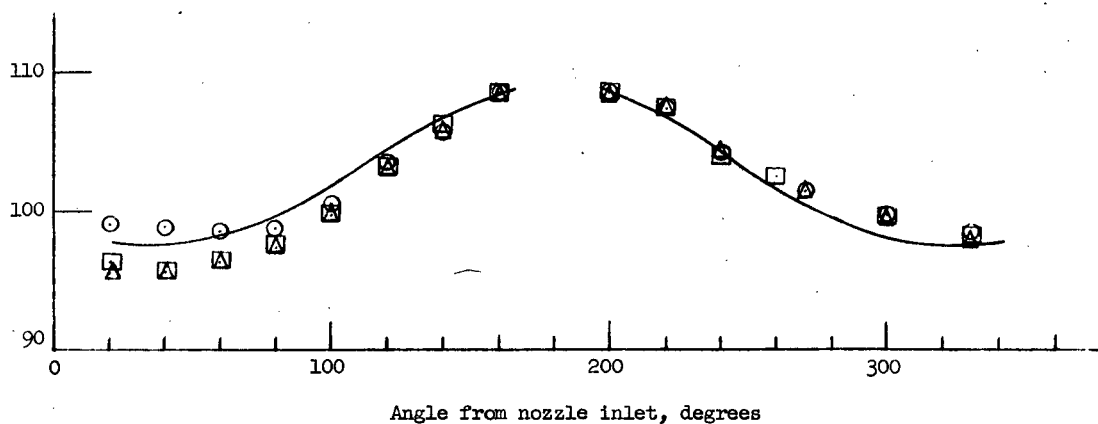
a. Pressure ratio, 1.23; jet velocity, 179 m/sec.

b. Pressure ratio, 1.39; jet velocity, 223 m/sec.

c. Pressure ratio, 1.70; jet velocity, 278 m/sec.

Figure 13. The effect of nozzle height and fore and aft location with respect to the wing on the noise radiation pattern at various pressure ratios. Circular nozzle; covered slots.

a. Pressure ratio, 1.23; jet velocity, 180 m/sec.

b. Pressure ratio, 1.39; jet velocity, 223 m/sec.

c. Pressure ratio, 1.70; jet velocity, 279 m/sec.

Figure 14. Effect of wing shielding on the sideline noise at various pressure ratios. Circular nozzle; nozzle location, c_1.
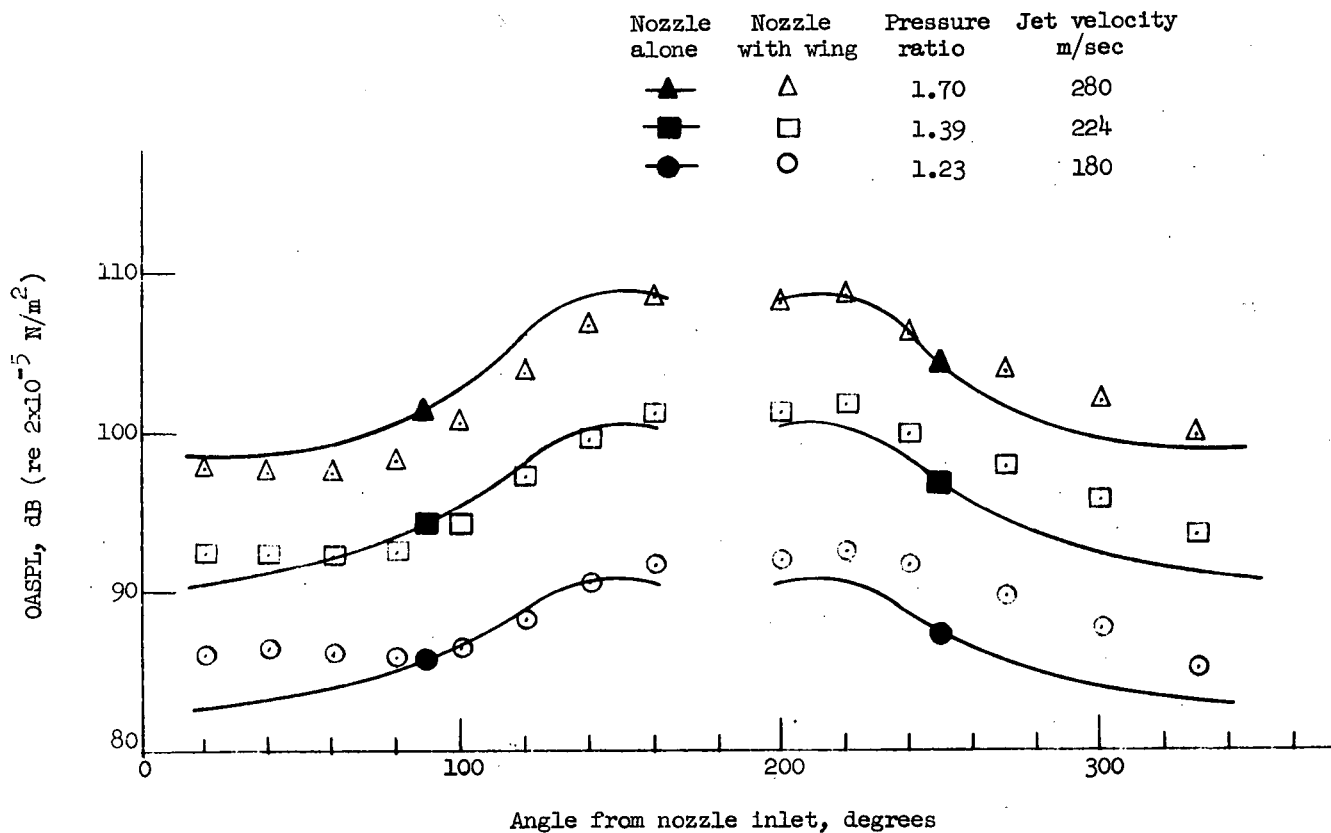
Figure 15. Effect of wing shielding on the sideline noise at various pressure ratios. Slot nozzle; nozzle location, c_1; covered slots.
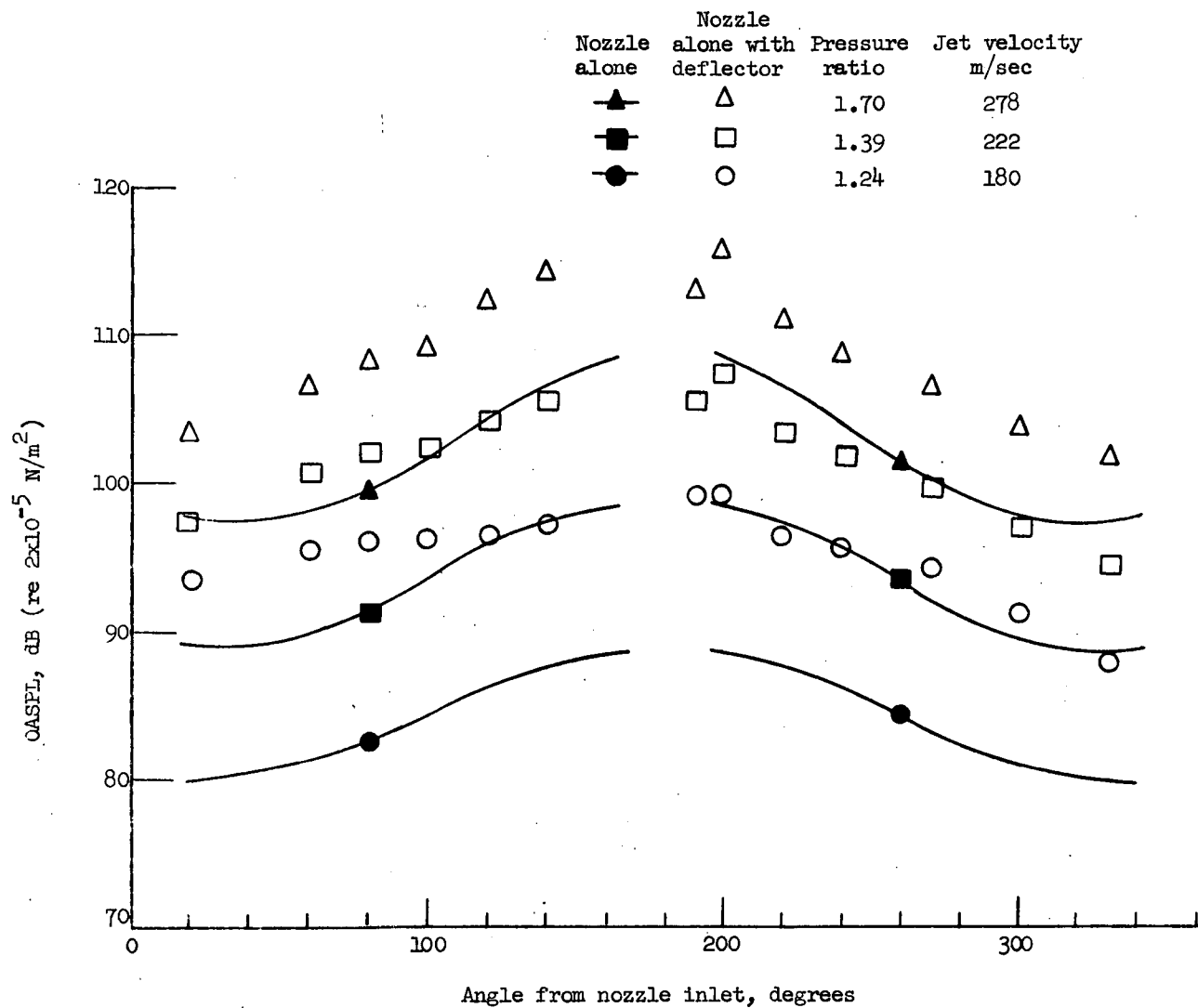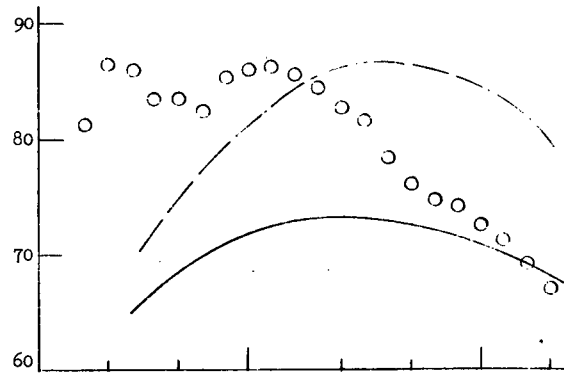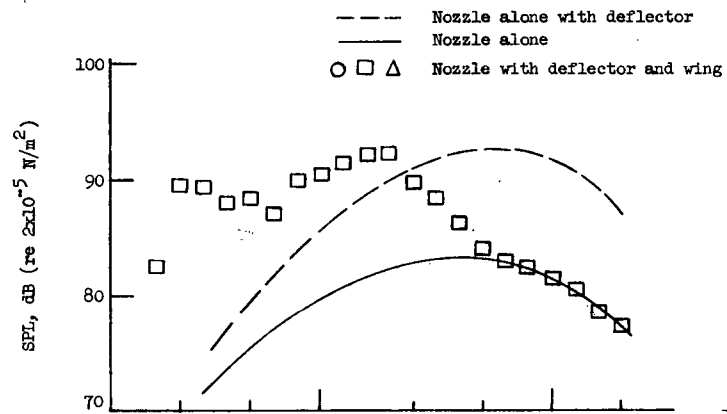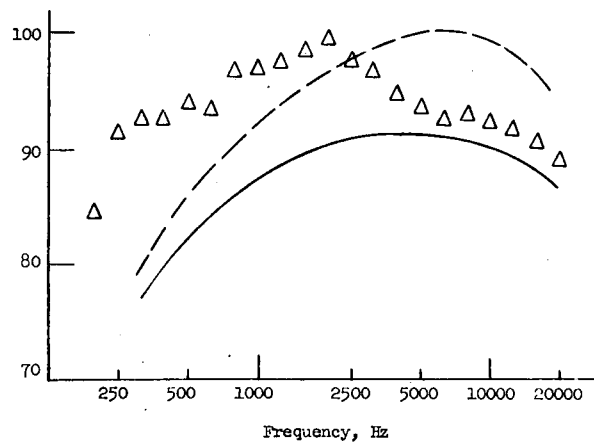
Figure 16. Noise data for the circular nozzle alone with a flow deflector at various pressure ratios.

a. Pressure ratio, 1.26; jet velocity, 189 m/sec.

- - - - Nozzle alone with deflector
———— Nozzle alone
O □ △ Nozzle with deflector and wing

b. Pressure ratio, 1.39; jet velocity, 225 m/sec.

c. Pressure ratio, 1.70; jet velocity, 280 m/sec.

Figure 17. The effect of a flow deflector on wing shielding as a function of the 1/3 octave band frequency at various pressure ratios. Microphone angle, 100°; circular nozzle; nozzle location, c_1; covered slots.

Legend:

— — — Nozzle alone with deflector
————   Nozzle alone
○ Slots uncovered
◻ 10.2 cm wide tape covering 2nd slot
◇ 10.2 cm wide tape covering 1st slot
☐ 10.2 cm wide tape covering both slots
△ Slots completely covered

a. Pressure ratio, 1.26; jet velocity, 189 m/sec

b. Pressure ratio, 1.39; jet velocity, 225 m/sec.

c. Pressure ratio, 1.70; jet velocity, 280 m/sec.

Angle from nozzle inlet, degrees
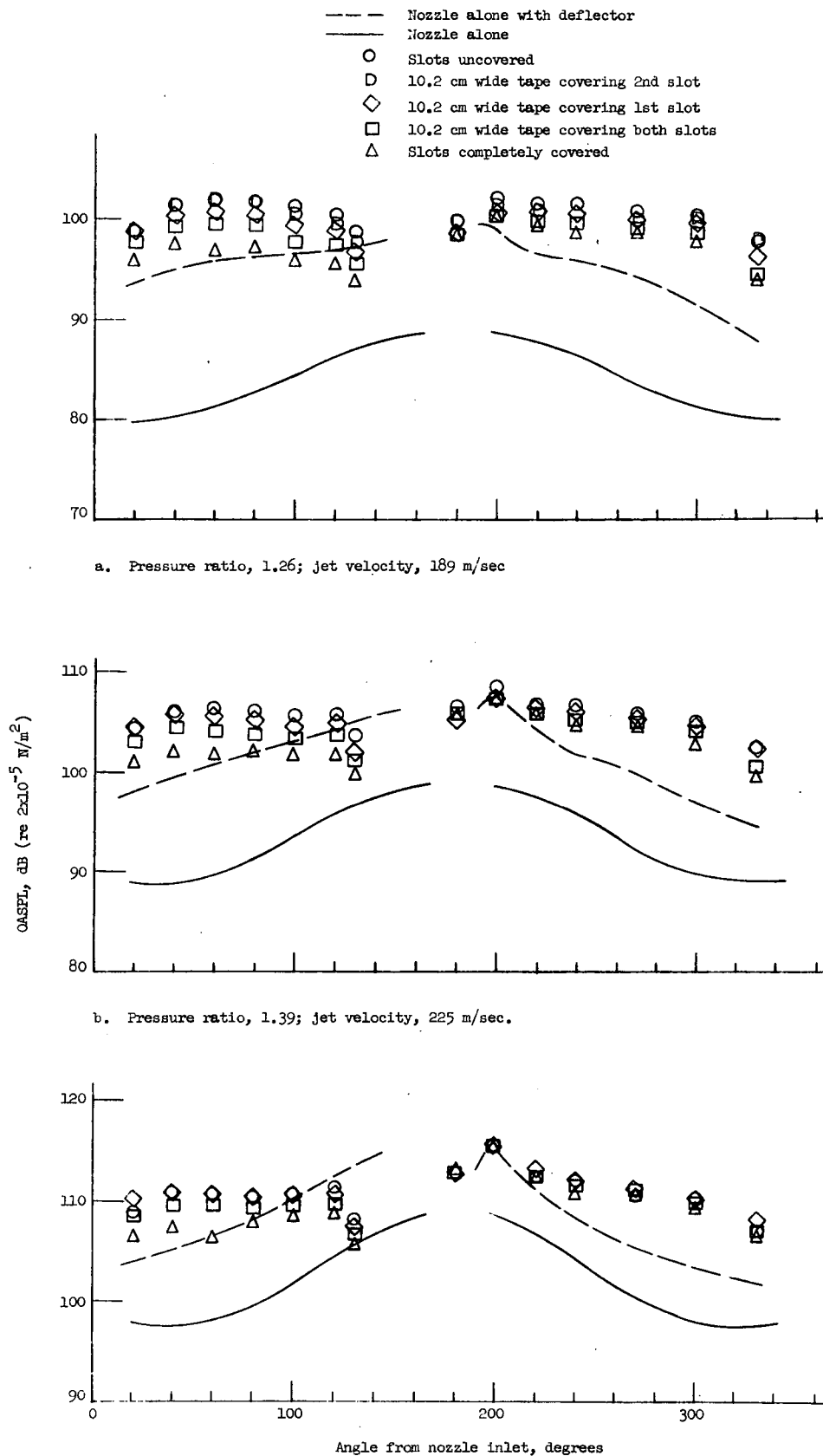
OASPL, dB (re 2×10^{-5} N/m^2)

Figure 15. The effect of a flow deflector attached to the nozzle on the noise radiation pattern at various pressure ratios and with various degrees of slot cover; circular nozzle; nozzle location, c_1.
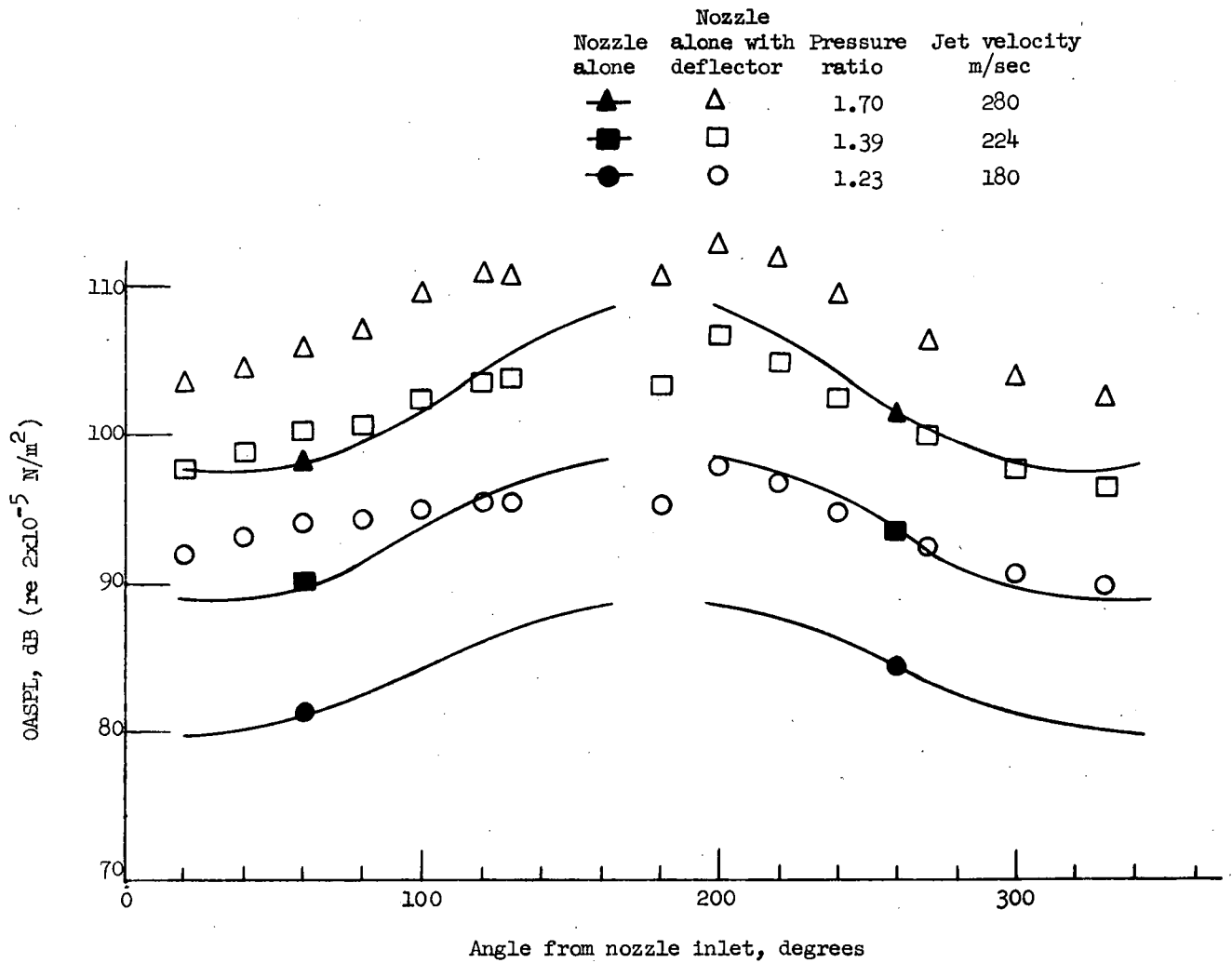
Figure 19. Sideline noise data for the circular nozzle alone with a flow deflector at various pressure ratios.
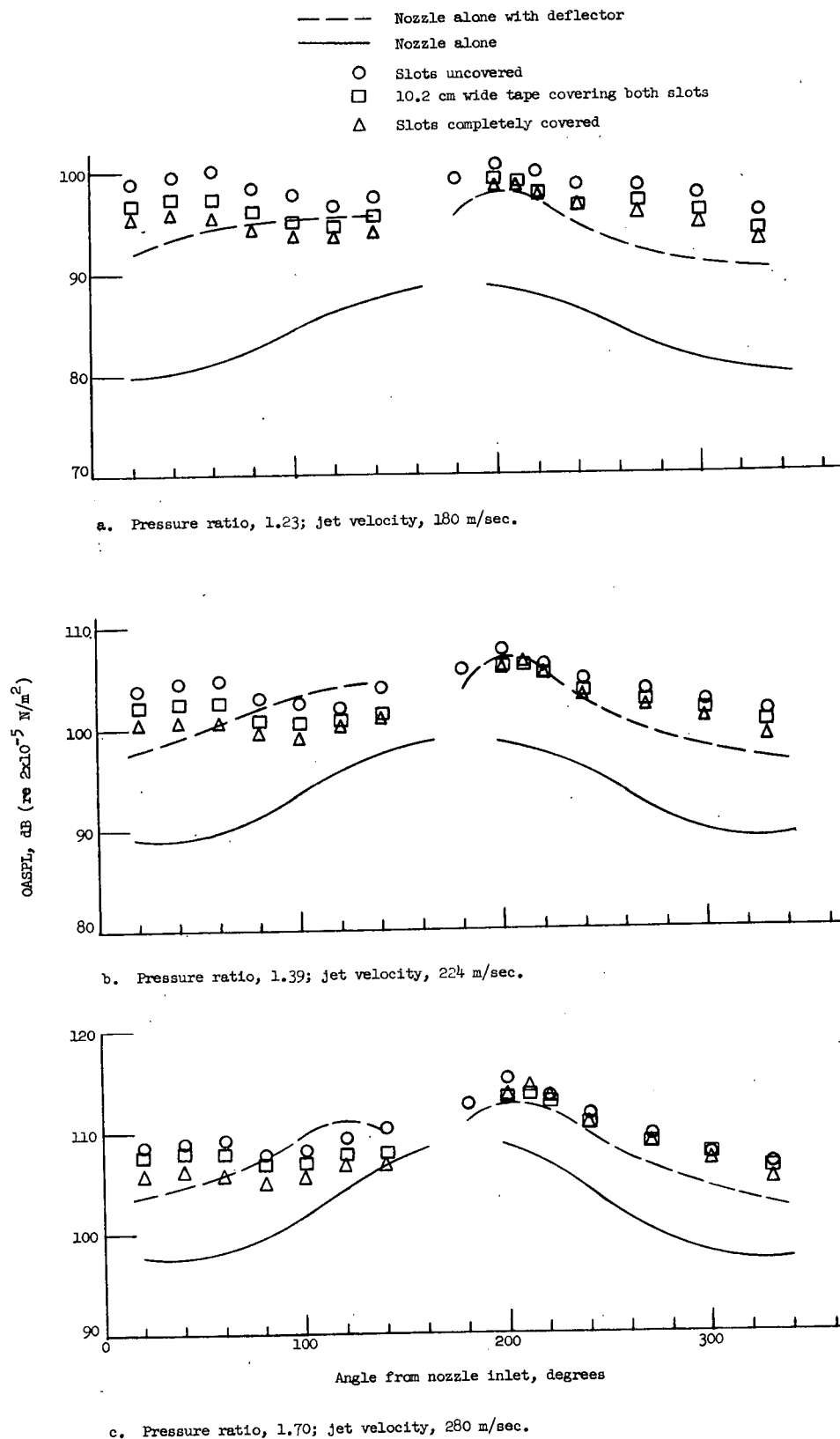
Legend:
— — — — Nozzle alone with deflector
———— Nozzle alone
○ Slots uncovered
□ 10.2 cm wide tape covering both slots
△ Slots completely covered

a. Pressure ratio, 1.23; jet velocity, 180 m/sec.

b. Pressure ratio, 1.39; jet velocity, 224 m/sec.

c. Pressure ratio, 1.70; jet velocity, 280 m/sec.

OASPL, dB (re 2×10^{-5} N/m²)
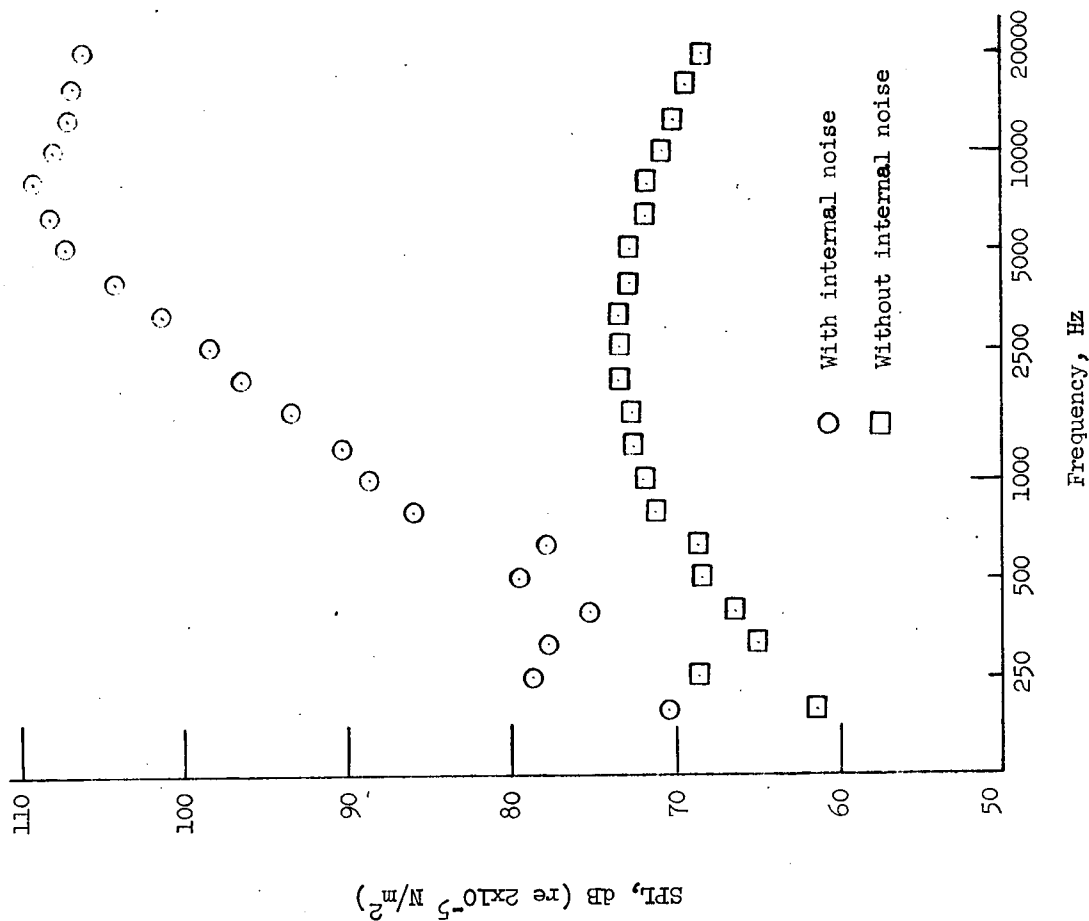
Angle from nozzle inlet, degrees

Figure 20. The effect of a flow deflector attached to the nozzle on the sideline noise radiation pattern at various pressure ratios and with various degrees of slot covering. Circular nozzle; nozzle location, c_1.
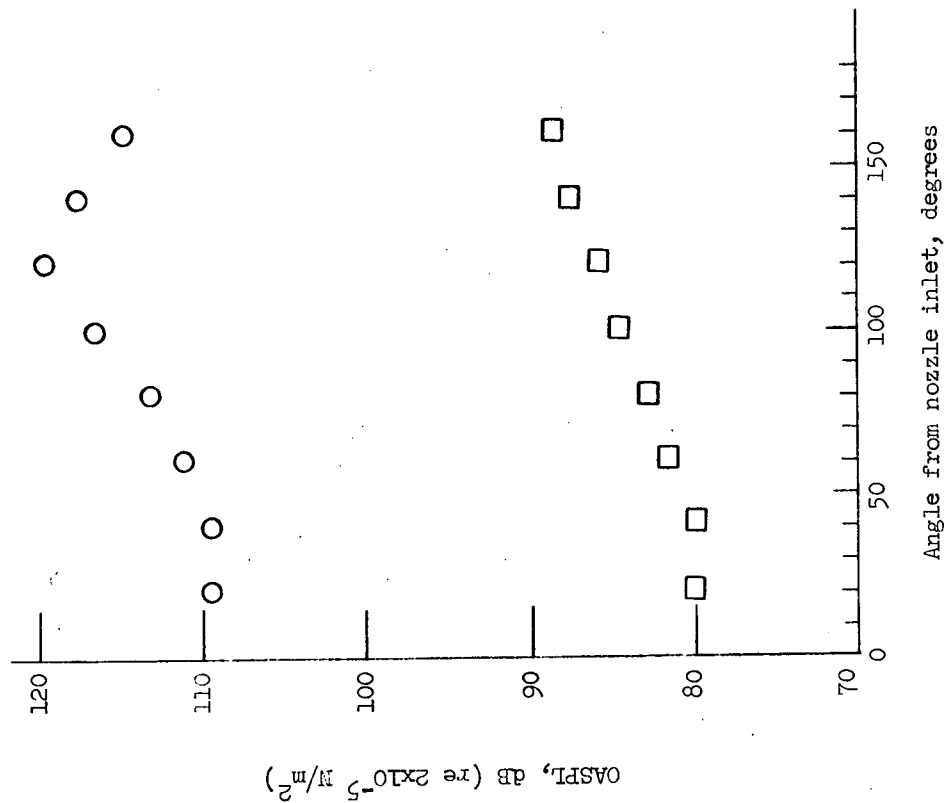
a. Noise radiation pattern.

b. One-third octave band sound pressure level spectra. Pressure ratio, 1.23; jet at 100°.

Figure 21. Illustration of the internal noise source with a circular nozzle alone. Pressure ratio, 1.23; jet velocity, 179 m/sec.
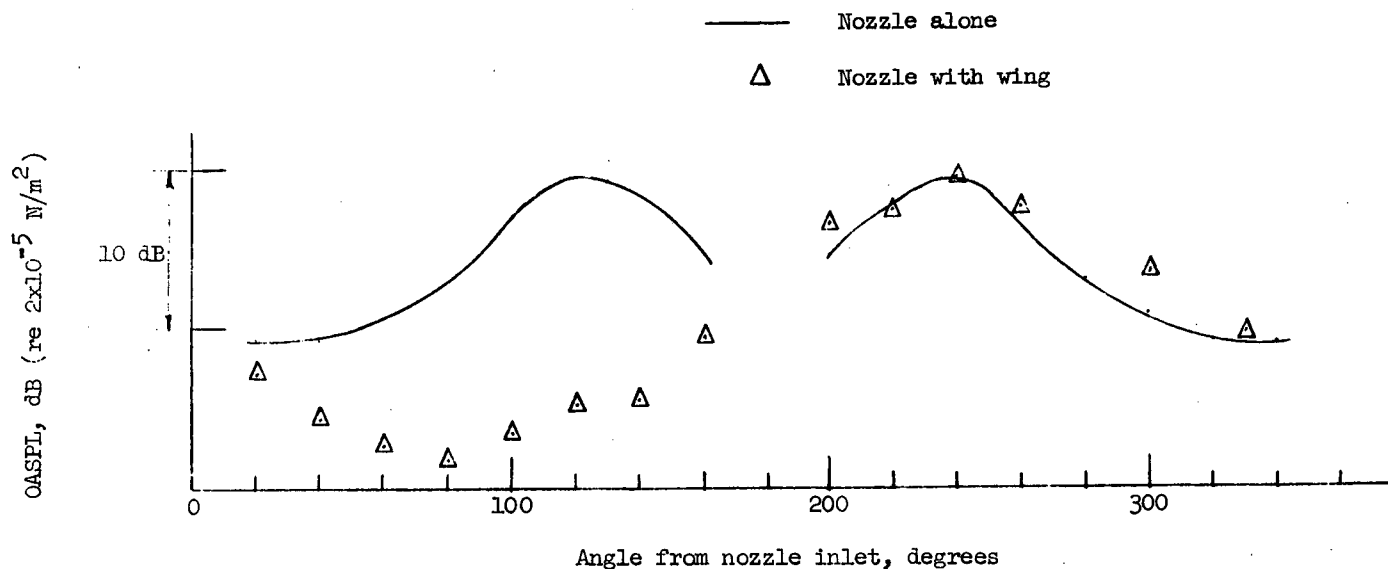
Figure 22. Effect of wing shielding on the noise radiation pattern with a dominant internal noise source. Pressure ratio, 1.24; jet velocity, 181 m/sec; circular nozzle; nozzle location, c_1; covered slots.
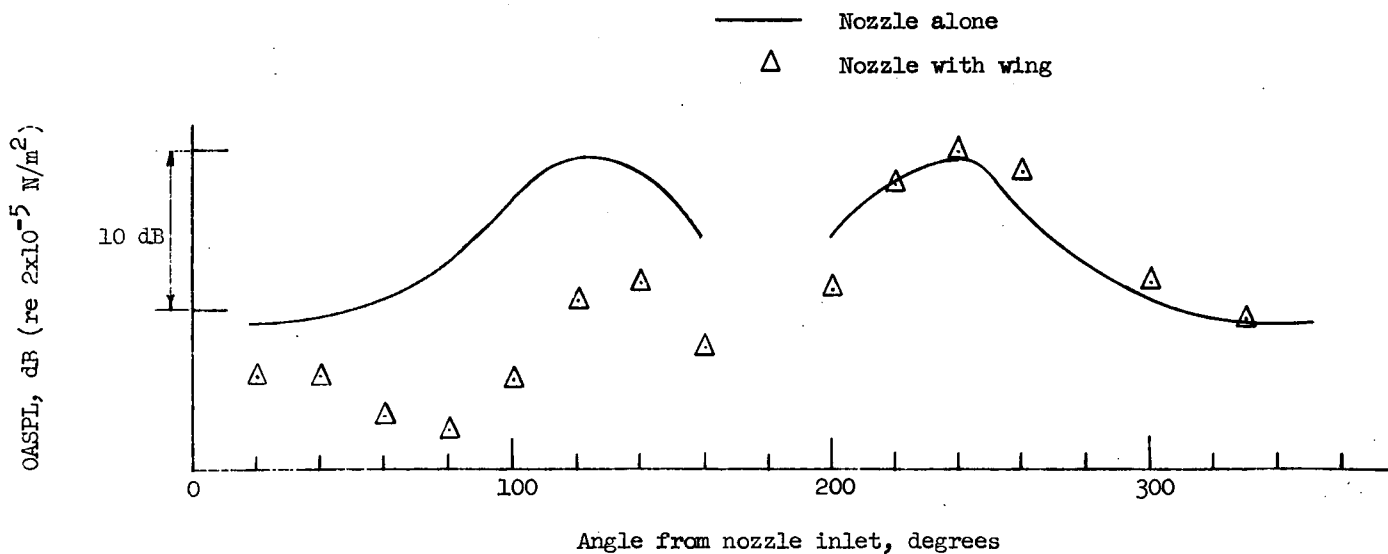

Figure 23. Effect of wing shielding on the sideline noise with a dominant internal noise source. Pressure ratio, 1.24, jet velocity, 181 m/sec; circular nozzle; nozzle location, c_1; covered slots.